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Why Mission Threads Aren't Good Enough

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June 9, 1997

Abstract

For many years military command-and-control systems have been evaluated by the use of mission threads. Mission threads arise from operational requirements and are designed so that a system's response to a series of selected scenario events can be quantified. They may be used to answer timeline and routing questions such as: "How long does it take to complete a mission?" "How can information be more effectively routed?" "Where are the delays in the mission threads occurring?". While these descriptive data are sufficient for the decision maker to judge a prototype command-and-control system on a pass/fail basis, they do not convey information about the performance of the communications subsystem; in particular, they do not allow the accurate determination of throughput and delays. Mission threads do not allow human effects to be satisfactorily decoupled from the communications effects, thereby inhibiting the characterization of the types of delays a system may be experiencing. An in-house solution has been to generate "messages" that are simply character strings of a specified length and arrival rate. Test and evaluation software inserts the message strings into the communications system, and allows network statistics to be made accessible to the decision maker in an accurate and timely fashion. This paper describes the nature of mission threads, problems encountered with their use, and the effective use of message strings in experimentation.

Introduction

For many years the evaluation of military command-and-control (C2) systems has been dominated by the use of mission threads. Mission threads are a time-ordered series of messages required to perform an operational task. For example, if there is an operational need to be able to place artillery rounds on a target within 2 minutes of the forward observer's (FO) call for fire, then the C2 system must be able to send the various requests and commands about the battlefield to accomplish this task within the specified time constraints.

Once a C2 system is created, evaluation is required. With most systems evaluation consists of taking the system to the field, using it with troops in simulated maneuvers, and having observers record the times various events occur. These times are then compared to the operational requirements, and the system either passes or fails. Unfortunately, testing in this manner is expensive and often fails to pinpoint bottlenecks or problem areas. Our premise is that while mission threads are necessary for the final evaluation of C2 systems, they are not sufficient for the evaluation of today's digital C2 systems.

Decentralized battlefield C2 requires reliable and timely distribution of information. Presently, information distribution is limited by noisy channels and protocols that do not match the channel to traffic demands, forcing commanders to make decisions with out of date or incomplete information. Experimental use of message strings (arbitrary data used to provide communications loading) allows for a much broader-based effort, emphasizing network adaptations at the lower levels of the network protocol and taking into account channel and workload characteristics but not application-specific information. This approach encourages general adaptations that improve performance without actually cutting back on the information delivered.

It is our premise that by initially evaluating C2 communications systems using message strings, experiments involving the entire system can be better focused on military factors with a validated knowledge of the service the communications system can provide. In this paper we describe several experiments in which mission threads were used as the primary evaluation tool. We also describe an experiment in which message strings were used to provide a background for a system evaluation.

C3 System Evaluation Using Mission Threads

During the 1980s, the U.S. Army Research Laboratory (ARL)(then the Ballistic Research Laboratory) participated in a series of command, control, and communications (C3) experiments. These experiments were designed to investigate C3 issues associated with such things as new digital devices and digital communications links.

The first of these, the Fire Support Team (FIST) Experiment [1], was the first statistically sound test of its kind in which military players were interfaced with automated C2 equipment, and researchers were provided with a sound database of actual parameters measured during a controlled laboratory experiment. This experiment was conducted from May through June 1983 at the joint Human Engineering Laboratory (HEL)/Ballistic Research Laboratory (BRL) Command Post Exercise Research Facility (CPXRF). The experiment was designed to study the effects of message intensity and communications degradation on the FIST Headquarters' (HQ) ability to perform fire support coordination with a newly developed FIST Digital Message Device (DMD). From an analysis of variance (ANOVA) on the data collected, it was concluded that communications degradation and intensity had a statistically significant effect on the message traffic through the FIST HQ. Based on the results of statistical analyses, including ANOVA, contingency table analysis, and modeling techniques, many software enhancements were recommended for the FIST DMD.

In April and May of 1984, the FIST Force Development, Testing, and Experimentation II (FDT&E II) [2], a large-scale field experiment, was conducted at Fort Riley, KS. This was the first time extensive tactical, digital, Army C3 data were collected from a tactical fire direction system (TACFIRE) in a field environment. A factorial experiment was designed to study the FIST HQ ability to perform fire support coordination under different forward observation controls, headquarters' configurations, and workload components. From the data collected, the FIST HQ ability to service fire missions under different headquarters' personnel configurations was not statistically significant. However, forward observation controls and workload components had a significant impact on the median time required to service fire missions. Other statistical analyses, including cluster analysis, kernel density estimation procedures, and descriptive statistics, provided additional meaningful information about the data collected. For instance, the fire direction radio net was used, on average, 23.3% of the time. In a combat environment, this would provide the enemy with ample opportunity to detect and destroy the friendly units attached to this net. During the experiment, all messages were preceded by a 2.1-second preamble (which allowed the radios to reach good transmission operating conditions). If the preamble could be reduced to 0 seconds, theoretical computations revealed that the average net usage would drop from 23.3% to 5.9%. Other analyses of the FIST FDT&E II data provided similar-type ideas for improving field communications and equipment.

In December 1985, the Firepower Control Experiment, the second C3 experiment conducted in the HEL/BRL CPXRF [3], was designed to investigate the digital communications links between the Field Artillery battery Fire Direction Center (FA btry FDC) and simulated 155-mm howitzer units. In investigating the digital communications on the net linking the FA btry FDC and 155-mm howitzers, average net utilization was 26.7%. Since the minimum message preamble was used, 240 milliseconds, this suggested careful consideration should be given to the radios that would link the FA btry FDC and future semi-autonomous howitzers.

A measure of performance (MOP) is a response that is used to quantify the effects of the factors being evaluated during an experiment. For these three experiments, typical MOPs were service times (e.g., elapsed time from target acquisition until a fire request message is transmitted from a digital device) and network utilization. Analysis of these, and similar, MOPs enables an evaluator to state whether the system as a whole meets specific requirements, but does not enable him/her to identify general problem areas.

Let us revisit the operational need to place artillery rounds on a target within a 2-minute window of opportunity from the time of the FO's call for fire as a Fire For Effect (FFE) Mission Thread. Then, at a minimum, we need to address the events shown in Table 1.

TABLE 1.—*Mission Thread Events*

The time for the FO to enter the call for fire into the system	15 seconds
The time for the call for fire to get from the FO to the Fire Direction Officer (FDO)	X
The time for the FDO to process the call for fire	15 seconds
The time for the call for fire to get from the FDO to the battery	Y
The time for the gun crew to lay, load, and fire the round(s)	45 seconds
The time of flight of the round(s)	25 seconds

The times allowed for each of these events may be determined from training manuals, field experiments, and simulations. For our example, let's assume the values shown previously. This means the communications portion of the proposed C3 system must be able to transport the required messages within the constraint of

$$X + Y <= 20 \ seconds.$$

Of course, "real world" mission threads are more complex than this, but one can begin to see how system requirements are obtained.

A common element of the three experiments was that input was provided by tactical scenario databases that contained mission threads. These scripted scenario input files, coupled with appropriate timing parameters, were utilized to maintain the flow of the fire mission segments in the experiments. Typically, creating scenarios for use with well-defined experimental designs is a time-consuming process. For example, the scenario created for the FIST Experiment required that several criteria be imposed to ensure that task loading on the FIST HQ didn't vary significantly between test cells of the same message intensity (e.g., the ratio of FFE to Adjust Fire (AF) missions was chosen as 2:1, the number of adjustments in each AF was chosen as three, and one fire mission in each 2-hour test cell was designated as urgent rather than normal priority). It was also realized that the time interval between fire missions was a significant factor that influenced the loading on the FIST HQ. Since timing wasn't specified in the original scenario definition, all fire mission time-tags were changed manually so that the intervals between the fire missions were the same for each cell of the same intensity. This procedure alone took 60 man-hours. Similar problems presented themselves in the development of tactical scenarios for the FST&E II and the Firepower Control Experiment.

C3 System Evaluation Using Message Strings

The networks that are of particular interest to the Army have nodes with high computing power but weak, noisy, shared communications links. Our current approach to communications emphasizes working intelligently at each node to limit or redirect the amount of information that must be passed along the channel. Each node is assumed to act independently to improve the effectiveness of the information exchange between nodes. Such a system of controls requires that each node be able to: monitor the network traffic; decide whether performance is inadequate; and, if so, make an adjustment to the protocol to improve performance. In general, the objective is to maximize network throughput while minimizing delay in the delivery of information to the end user. Protocol parameters such as packet size, coding technique, and channel access algorithm could be adjusted to improve or optimize information transfer. Identifying the right tool can often render a seemingly impossible problem tractable: message strings offer us just such a tool.

In April 1991, Program Manager - Advanced Field Artillery Tactical Data System (PM AFATDS) visited BRL to discuss a Magnavox study that addressed AFATDS communications over Combat Net Radios (CNRs) via the Tactical Fire Direction System (TACFIRE) protocol [4]. PM-AFATDS wanted an independent assessment of the results of that study, which indicated network saturation for various portions of their proposed scenarios.

The BRL's Firepower Control facility was used to build, load, and monitor four AFATDS nodes sharing a single network and communicating over CNRs. Each node consisted of a SUN workstation and a Magnavox tactical communications modem (TCM) to enable communications via SINgle-Channel Ground and Airborne Radio System (SINCGARS) radios. The TCMs contained the carrier sense multiple-access algorithm used by the TACFIRE communications protocol. Each node also contained a message driver, providing communications loading, and data collection software to log the sending and receipt of messages, as well as information on queues. A controlled laboratory experiment was conducted to quantify the effects of message length, message transmission rate, and frequency hopping on the network throughput and delay requirements expected to be placed on AFATDS [5].

In place of the more commonly used mission threads, a scenario generator was written to create "messages" of character strings (0s and 1s) of a specified length and arrival rate [1] over a 1-hour period. The intent of using strings is to emulate the anticipated actual operation of a network without incorporating actual "scripted" scenarios. Their use also allows the experimenter to easily extend the range of consideration to include communications load levels that exceed the theoretical capacity of the network in question, thus more expeditiously predicting and accurately representing dynamic field conditions.

Four message arrival rates emulated the rate of actual user-generated messages and specific nodes' ability to respond to incoming messages. Message lengths were chosen based on the message lengths used by Magnavox (e.g., the 48-character message corresponded to the

[1]The theoretical capacity of a communications network is commonly expressed in terms of a Poisson distributed random variable with exponentially distributed inter-arrival times. Even though we know that field conditions do not present an exponential distribution of events, it is the best with which we have to work.

Magnavox 576-bit message). The messages were equally distributed among the four nodes. For example, if the expected arrival rate to the network was 2,000 messages/hour, the scenario generator created a file of 500 messages for each node. A message was assumed to enter network service when it reached the modem.

Once the message was generated, the communications protocol added several layers of information to ensure the message arrived at its destination. This included 5 error detection/correction bits for each 7-bit character, 4 synchronization characters, and a preamble to bring the transmitter to full power before the message was sent. Acknowledgments (ACKs), though shorter in length, were wrapped with similar overhead bits. Figure 1 illustrates the

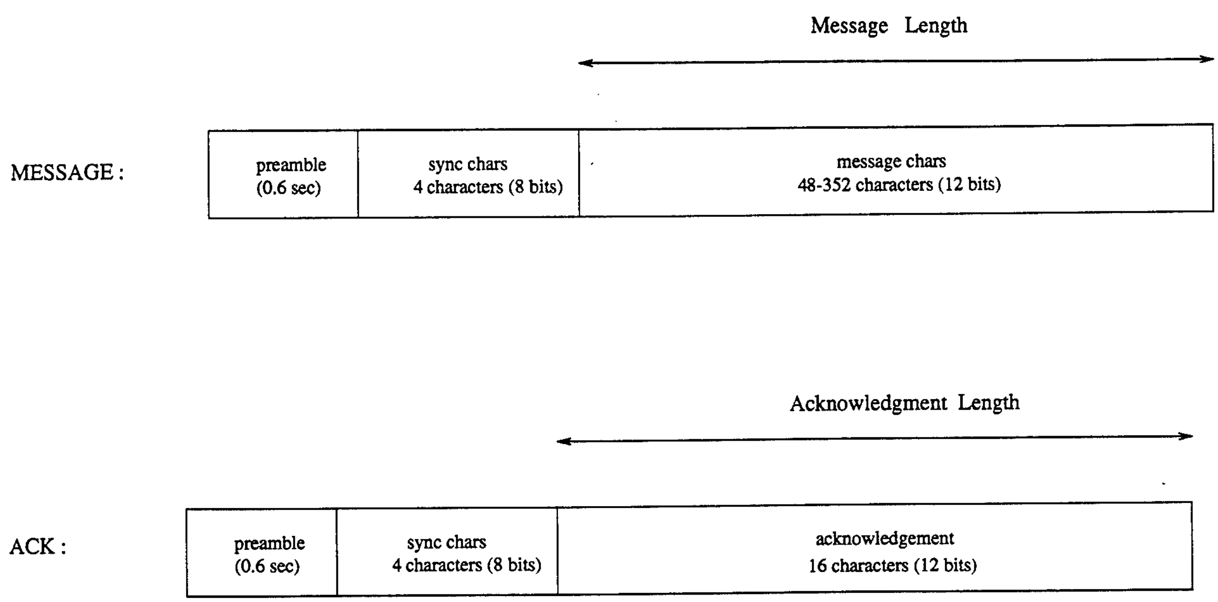

FIGURE 1.—*The Components of Messages and Acknowledgments*

message and acknowledgment components.

The data were collected in accordance with an incomplete block design to control for day-to-day variability. The experiment was replicated three times to ensure a balanced design [6].

The results of the AFATDS experiment with actual hardware and protocols provided valuable information on CNR thresholds and showed that even under benign laboratory conditions, there was inherent degradation, discounting the modeling assumption of "perfect" communications. The analyses concluded that SINCGARS radios employing the TACFIRE protocol would experience difficulty in accommodating the expected data rates of AFATDS. Average throughput in the experiment did not exceed 55% of the network's capacity (47% in frequency hopping mode). Utilization never exceeded 80%, while network delays were always greater than twice the message transmission time.

The experiment confirmed some information that was considered intuitive (e.g., as the message arrival rate increased, throughput also increased), but it also uncovered several anomalies of the TACFIRE protocol operating with SINCGARS radios. The following is a

partial list of some of those anomalies: 1) message transmission overhead is excessive; in general, the time to transmit the preamble is longer than the time necessary to transmit the actual information, 2) net access delay overrides message priority (i.e., the node with the shortest net access delay basically takes control of the entire network during high traffic periods; prioritizing messages within a node has little effect unless the priority scheme is passed to the modem in some way), 3) higher bit rates do not linearly increase throughput, and 4) frequency hopping increases the number of collisions.

These limits that were identified should be considered when modeling or designing communications architectures and protocols, and consideration should be given to future experimentation to evaluate those limits. The experimental results reaffirmed those critical issues which AFATDS developers addressed during the development of this complex C3 system.

Conclusion

In this paper we have shown how message strings may be used to simplify the testing and evaluation of C2 systems by limiting the more complex mission thread testing to those cases where the communications equipment can support the message load. Testing with message strings may also be combined with theoretical studies and simulations as shown in Figure 2 to provide a validated basis for both the design and test and evaluation of C2 systems.

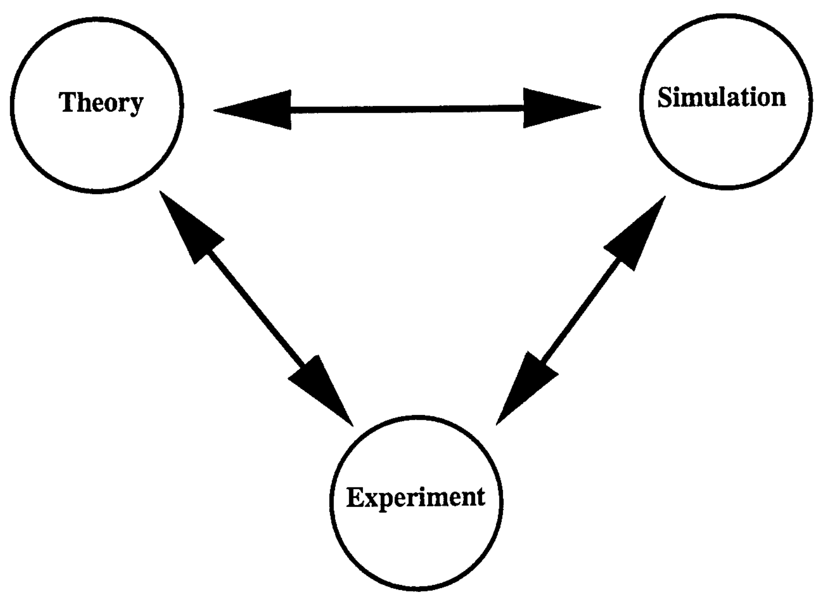

FIGURE 2.—*The Complete Simulation Cycle*

Experimentation provides the validated parameters for the theory and simulations, which in turn provide insights to the system performance as the C2 system is scaled to operational sizes.

Abbreviations

ACK	Acknowledgment
AF	Adjust Fire
AFATDS	Advanced Field Artillery Tactical Data System
ANOVA	Analysis of Variance
ARL	Army Research Laboratory
BRL	Ballistic Research Laboratory
btry	battery
C2	Command and Control
C3	Command, Control, and Communications
CNR	Combat Net Radio
CPXRF	Command Post Exercise Research Facility
DMD	Digital Message Device
EOM	End of Mission
FA	Field Artillery
FDC	Fire Direction Center
FDO	Fire Direction Officer
FDT&E II	Force Development, Testing, and Experimentation II
FFE	Fire for Effect
FIST	Fire Support Team
FO	Forward Observer
HEL	Human Engineering Laboratory
IDT	Information Distribution Technology
MOP	Measure of Performance
MTO	Message to Observer
PM	Program Manager
SHOT	Shot out
SINCGARS	Single Channel Ground and Airborne Radio System
TACFIRE	Tactical Fire Direction System
TCM	Tactical Communications Modem

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